Traffic management in optical communication networks

Field of the invention

The proposed invention relates to the field of optical communications.

Background of the invention

WO 02/23770 A1 describes a method of power control in an optical communication system, for reducing non-linear phenomena in optical fiber wave guides. In the system, by preliminarily determining thresholds of power leading to non-linearity, the radiation power transmitted from node to node is controlled to keep it stabilized at a predetermined level at which optical non-linearity are reduced to less than a predetermined threshold in the optical fiber wave guide.

All the operations and conclusions are based on power measurements and comparing thereof with pre-calculated power values.

JP 11266200 (EP 0944191A1) describes a method and a device for optical communication, to compensate for the wavelength dispersion and the nonlinearity and to attain the transmission of a long distance by controlling the chirp parameter to decrease the code errors of detected electric signals. A 1st end office device has an optical transmitter, which transmits the optical signals having the chirping that is decided by a chirp parameter to an optical fiber transmission line via its 1st terminal and a control unit, which controls the chirp parameter of the transmitter based on a control signal CS. Meanwhile, a 2nd end office device has an optical receiver, which converts the optical signals transmitted via the line into the electric signals and a monitor unit which detects the code errors of electric signals, which are outputted from the receiver. Then a receiving unit of the device produces the signal CS that is supplied to the control unit to decrease the code errors detected by the monitoring unit, for example. Thus, the chirp parameter is controlled.

According to the above technique, the chirp is introduced in the optical signal to be transmitted via the communication line and is changed in response to measuring the BER.

US 5463661 describes a two-wire modem and a method to select a carrier frequency, a transmitter power level and other parameters to communicate in a full duplex mode, based on received signal and echo characteristics of the communication media estimated by the modem using probing signals; for example, the TX preemphasis and TX power control processor estimates the signal characteristics including non-linear signal distortion of the communication media, and the probing signals include a chirp signal.

The above solution is specifically designed for a two-wire modem electric communication system; the phenomenon of chirp in the electric transmission media is different from that in the optic media.

Summary of the invention

The object of the proposed solution is to provide a new way of overcoming problems mainly caused by non-linearity in optical networks, based on a simple detection of such problems.

The above object can be achieved by providing a method of traffic management in an optical network, based on measuring chirp of optical signals transmitted along an optical path extending in said network.

The above method of traffic management in an optical network, wherein the optical path extends between a first location and a second location being a monitoring point and comprises one ore more optical channels carrying the optical signals, the method comprising:

- measuring chirp at least at one optical channel at the monitoring point;
- in response to the measured chirp, judging about a level of non-linearity in said at least one channel of the optical path up to the monitoring point,

- in case the non-linearity level is considered higher than a selected acceptable level, performing one or more traffic management operations to reduce said non-linearity level.

The step of measuring chirp preferably comprises measuring a second derivative, versus time, of phase of an optical signal transmitted via a particular optical channel.

It should be appreciated that the above-mentioned method can be performed at more than one optical channels of the optical path.

Preferably, the method comprises an additional step of repeating the method from the step of measuring the chirp, up to a moment when the non-linearity level, according to the measured chirp, is considered to be not higher than the selected acceptable level.

The first location, in the frame of the present description, is preferably a network element considered the beginning of the optical path. Such a network element, for example, may be capable of performing one or more of the following functions: transmitting, adding, regenerating, amplifying, switching, routing of optical signals in one or more of the optical channels. The second location may be any point of the network being just equipped with means for chirp measurement, or allowing applying such means.

The traffic management operations are to be understood as one or more selected from the following non-exhaustive list:

-reducing bit rate of at least one of said optical channels;

-rerouting at least one of said optical channels;

-reducing a number of optical channels in the trail;

-transmitting information, previously carried at a specific wavelength, via a vacant optical channel of the same optical path at a different wavelength (so-called frequency hopping).

The operation of rerouting of said at least one optical channel can be performed, for example, by:

- routing the optical signals of one or more of the optical channels for regeneration, and returning said signals back to said optical path,
- routing one or more of the optical channels via a different optical path and returning them to the monitoring point via said different path.

The operation of reducing the number of optical channels can be performed, for instance, by temporarily ceasing transmission of some optical channels via the optical path. It can also be reached, for example, by stopping transmission of add channels via OADM (Optical Add Drop Multiplexer) situated in the optical path.

Actually, if the operation of re-routing some channels is performed via a different optical path, which does not arrive to the monitoring point, it becomes equivalent to the operation of reducing the number of optical channels.

The mentioned acceptable level of non-linearity for a particular optical path can be defined by selecting a threshold value presented by a threshold (maximally acceptable) chirp value, or presented by a threshold (maximally acceptable) bit error rate value (BER). Alternatively, the acceptable level of non-linearity can be defined by selecting a chirp values range, or a mixed chirp/BER values range.

The chirp value range can be selected, for example, based on the exact chirp calculation for the "linear" optical path. Say, the range may be formed by so-called " absolute chirp value" for the linear case and a chirp value exceeding the absolute value by some percent.

Alternatively, the range can be selected using two values for chirp in the optical path being in two somehow differing "non-linear" conditions.

Another option is selecting one (minimal) value of the range to be the absolute chirp value obtained from the exact calculation of the linear optical path, and the other (threshold) value – as a chirp value obtained, for example, from a numerical solution for a non-linear optical path.

Actually, there is yet another option: the lower bound of the range may be selected as a particular chirp value (for example, the absolute chirp value for the linear optical path) and the higher bound of the range – as a maximal

acceptable BER value corresponding to a number of chirp values for a number of bit rates.

For the step of judging about a present level of non-linearity, the method preferably comprises performing at least one of the following preliminary operations:

a) calculating chirp for a linear condition of said optical path for at least one of said optical channels, and selecting at least one absolute chirp value based on said calculation,

b) building a number of curves for at least one of said optical channels, wherein each curve reflects dependence between the real chirp and BER at a particular bit rate of optical transmission; and selecting at least a maximal acceptable BER value (corresponding to more than one chirp values associated with different bit rates);

c) obtaining one or more numerical solutions for a real chirp in at least one optical channel of said optical path being in some non-linear condition(s); and selecting at least one real chirp threshold value based on said solutions.

When speaking about "at least one" absolute chirp value or real chirp value, one should understand that different values are usually obtained for respective different points of the optical path, and for different channels. Moreover, different chirp values can be obtained for defining ranges of acceptable non-linearity.

In view of the above, the decision about the present level of non-linearity can be made according to either a " hard decision approach", or a "soft decision approach".

The hard decision approach suits for maintaining linearity of optical lines and means taking the traffic management steps whenever the measured chirp exceeds the absolute chirp value calculated for the linear system.

The soft approach means taking the traffic management steps only when the optical path passes into the condition more non-linear than a so-called "acceptably" non-linear condition (range). The upper bound of such range can

be defined either by a selected threshold chirp value different from that of the linear system, or by a selected maximal acceptable BER value for the particular optical channel.

In view of the above, the decision-making may constitute a single step decision or a double-step decision.

The single step decision implies taking traffic management steps whenever the absolute chirp value is exceeded.

In the double-step decision, for example, upon exceeding the absolute chirp value, only partial traffic management steps can be taken or preparations for that can be made. Upon exceeding the non-linearity range (say, upon obtaining a measured chirp corresponding to a BER value exceeding the maximally acceptable BER for the particular optical channel), more or all the required traffic management steps can be performed.

Chirp for the linear condition of a particular optical path can be calculated using a model which describes a multi-channel optical path by a known system of non-linear Schrödinger equations (NLSE), each one for a particular optical channel in the path, taken without their non-linear terms. For the linear case, the model has an exact solution in the form of a Gaussian pulse, which includes a variable of chirp *c(z)*depending on the length of the trail.

For an exemplary case where the number of optical channels is two, the system of Schrödinger equations can be presented as follows:

$$i\frac{\partial u}{\partial z}+\frac{1}{2}[D(z)+D_0]\frac{\partial^2 u}{\partial \tau^2}+G(z)(|u|^2+2|v|^2)u=0$$

$$i\frac{\partial v}{\partial z}-ik\frac{\partial^2 v}{\partial \tau^2}v_\tau+\frac{1}{2}[D(z)+D_0]\frac{\partial^2 v}{\partial \tau^2}v_{\tau\tau}+G(z)(|v|^2+2|u|^2)v=0$$

where $\tau = t - z/V_0$, (*z, t* and V_0 are the propagation distance along the fiber, time and group velocity of the carrier wave), *k* is inverse-group-velocity difference between the channels, D_0 is average value of the dispersion

coefficient, i is $\sqrt{-1}$, D_z is the periodically compensated local dispersion map of the form:

$$D(z)=\begin{cases} D_+, if\, 0<z<L_+ \\ D_-, if L_+<z<L_- \end{cases} \quad (3)$$

where L+ is an optical path's section with anomaly dispersion, and L- is a section, of the optical path, with normal dispersion; and where the function G(z) is:

$$G(z)=\exp[-2\gamma z+2\Gamma\int_0^z\sum_n \delta(z-Ln)dz] \quad (4)$$

where γ is the fiber-loss parameter, and $\Gamma$is the amplifier's gain coefficient accounts for loss and gain in the fiber optical path, and L_n is the distance between amplifiers in the optical path.

The non-linear terms $|u|^2$ and $|v|^2$ in equations (1) and (2) represent the self-phase modulation and cross-phase modulation (SPM and XPM), respectively. In the limit of the linear system (with the SPM and XPM terms dropped in equations (1) and (2), the model has a well-known exact solution in the form of the Gaussian pulse which can be represented in the form:

$$u_0(z,\tau)=a(z)\exp[-\frac{\tau^2}{W^2(z)}+ic(z)\tau^2+i\phi] \quad (5)$$

where $a(z)$ is the complex amplitude, $W(z)$ is real width, ϕ is a phase constant and $c(z)$ is the real chirp.

For a non-linear system (say, for two optical channels with non-linearity effects), the real chirp values can be obtained from solutions of the equations (1) and (2).

Further, the method can be performed at a number of monitoring points in the optical network, thereby ensuring monitoring of non-linearity effects at optical sections of the network formed between said monitoring points and

performing various traffic management operations for reducing these effects at suitable sections, according to the proposed invention.

The prior art references which have been found never proposed to use a relatively simple operation of measuring chirp, occurring in the received signal, as a tool for determining the extent of non-linearity in optical transmission media in real optical networks which have changeable parameters and conditions. Neither of the prior art references proposes controlling traffic in the network based on measuring chirp.

Brief description of the drawings

Details of the proposed method will be further described and illustrated with the aid of the following non-limiting drawings in which:

Fig. 1a schematically illustrates a path in an optical communication network, comprising a number of monitoring points.

Fig. 1b shows a chirp behavior diagram schematically illustrating a case when optical path of Fig. 1a is linear.

Fig. 1c shows a chirp behavior diagram schematically illustrating a case where the optical path of Fig. 1a is non-linear.

Fig. 2 shows a look-up table schematically illustrating dependence between bit error rate (BER) and chirp, built for different bit rates of signal transmission for a particular optical channel.

Fig. 3 schematically illustrates the principle of traffic management, using an example of the ring network architecture and the method according to the invention.

Fig. 4 schematically illustrates another example of initiating traffic management operations in response to the chirp measurement according to the invention and using an example of a mesh network.

Detailed description of the invention

Fig. 1a shows an optical path (chain) 10 comprising a number of optical elements and a number of monitoring points, wherein three monitoring points

are respectively marked P1, P2, P3. In this particular example, the chain consists of spans each terminating with a DCM (dispersion compensation module) and the monitoring points are positioned after the respective DCMs.. It should be appreciated, however, that the monitoring point(s) can be placed at any other point(s) along the optical path. We consider that if the optical path 10 (comprising a number of optical elements connected by fibers) is linear i.e., not demonstrating non-linear effects, distortion of optical signals and chirp may appear in it mainly due to effects of chromatic dispersion.

The dispersion effects can at least partially be compensated by the DCM elements, and that is illustrated in Fig. 1b, where chirp appears and grows with the distance "z" between the monitoring points, or just with the number of spans (curve 12) . The chirp curve can be calculated by obtaining chirp values of a linear system, using the equations mentioned above; alternatively, the curve can be obtained using numerical solutions of these same equations for a linear case. In this particular example, the curve 12 is obtained by a numerical simulation of the optical path shown in Fig. 1a.

Fig. 1c schematically illustrates how the optical path 10 behaves from the point of chirp when non-linear effects appear in it (line 14). The chirp grows with the distance "z", and its growth due to the non-linearity effects is schematically shown by a dotted curve 16. It should be noted that the character of the curve may be different, since Fig. 1c is a numeric simulation of the optical path of Fig. 1a upon introducing into that a particular non-linearity.

If, according to the invention, chirp is measured at a monitoring point (say, at P3) and its value corresponds to Cmeas.3, it is then compared with the chirp value, which is considered the threshold.

In the frame of the present application, we do not explain exact methods of measuring chirp. However, one may recall that the chirp can be measured at a monitoring point as a second time derivative of phase of optical signal transmitted via a particular optical channel.

Let in this example the predetermined threshold chirp value characterizing the acceptable level of non-linearity at the monitoring point P3 is Ccalc(3) =0

being the absolute chirp value for this point, i.e., the requirements to the optical path are very strict. Whenever the measured chirp value exceeds the threshold chirp value, the network manager will take traffic management steps to avoid the non-linearity effects in the optical path.

It should be noted that the threshold chirp value may be selected, say, to be a value exceeding the absolute calculated chirp of the linear system by a particular percent.

Alternatively, the threshold chirp value may be selected based on a numerical calculation performed for a non-linear optical path. It can be the chirp value for this monitoring point according to the curve 14, or a chirp value according to an additional numerical calculation curve (say, a curve giving a smaller chirp amplitude – not shown).

Yet another way of determining whether the optical path is still in the linear region, is checking BER corresponding to the measured chirp value. To do this, the network manager should be provided with look-up tables similar to those shown in Fig. 2, for one or more optical channels.

Fig. 2 shows a look-up table which comprises two exemplary curves log(BER)/chirp preliminarily built for the path 10, and corresponding to a particular optical channel at the transmission bit rate 10 GBps (the lower line) and at the bit rate 40 Gbps (the upper line). Chirp axis is marked by arbitrary units. In practice, quite a great number of curves corresponding to different bit rates can be preliminarily obtained for the particular optical channel. Consequently, each optical channel can be provided with a similar family of curves.

The curves are built by using numerical simulations using equations (1), (2) performed for one and the same optical path of Fig. 1a but for different bit rates.

When obtaining a measured value of the chirp (say, it is Cmeas.1) for the channel transmitting data at 40 Gbps, and when the corresponding BER exceeds the BERmax accepted for the channel, the network management system may consider reducing the bit rate via the problematic channel so that

the accepted level of BER be ensured. It can be carried out by finding two or more BER values on the look-up table, corresponding to the measured chirp value and to different bit rates, and selecting such a bit rate which ensures the accepted level of BER). In this example, the reduced bit rate may be the bit rate of 10 Gbps.

Multi-stage traffic management decisions can be taken in this case, when the measured chirp value indicates exceeding the acceptable non-linearity range. For example, some network management steps can be performed already upon exceeding the lower bound of the range (say, a particular chirp value), and the bit rate can be reduced if, by some reason, the non-linearity grows and BER exceeds the upper bound of the range (BERmax). Alternatively or in addition, other traffic management operations can be carried out at the upper and/or lower bounds of the range: for example, re-routing of the problematic optical channel can be performed, or the data can be transmitted via another optical channel in the same path to overcome influence of the non-linear effects.

Fig. 3 schematically illustrates an example of ring-like network where the method according to the invention can be applied.

Let the inner ring 20 of the ring network is the working optical path, and the outer ring 30 – is its protection optical path. Let OADM nodes 40 and 50 are capable of switching optical channels from one trail to another. Let, for example, there are three monitoring points in the working path 20: Pa, Pb an Pc. The ring network is provided with a traffic control unit in a network manager system NMS 60.

If, for example, a chirp value is measured at the monitoring point Pb by a chirp measurement unit 52, the reading is transmitted to the NMS 60. If it is decided in the NMS that the chirp value exceeds a particular accepted chirp/BER level (according to either technique of selecting that accepted level), the NMS 60 will be able to initiate transferring part of the optical channels of the path 20 which previously passed through the OADM 40, to pass via the protection path 30 in the opposite direction (see the dotted line 55). Thus, if such optical

channels must be received at OADM 50 of the network, they will be received at the OADM 50, just from the other direction.

The drawing illustrates an example of initiating the traffic management in response to a chirp measurement indicating some excessive non-linearity. In the example, particular optical channels are redirected (re-routed) which actually results in reducing the number of channels in the original optical path 20.

Fig. 4 illustrates another type of network, for example, a mesh network 70 comprising nodes 72, 74, 76, 78, 80, 82 and others. Let an optical path (trail) of the network between nodes 74 and 82 transmits four optical channels having respective carrier wavelengths λ2, λ3, λ4 added at node 72. The wavelength λ1is added at the node 74. Two channels λ2, λ3 are dropped at the node 80, and the remaining two channels λ1 and λ4 should arrive to the node 82 via a fiber 77. The network comprises a monitoring point at the node 82, where two chirp measurement units 84 and 86 measure chirp at respective two optical channels λ1 and λ4, for further transmitting the readings to a traffic management block 90.

Let, for example, the measured chirp at the channel λ1 exceeds the predetermined threshold and some traffic management operations are to be taken for reducing non-linearity of the optical path 77 + 75. The drawing schematically illustrates two optional traffic management operations which can be initiated by the traffic management unit 90.

The first possible traffic control operation is controlling nodes 74 (OADM) and 78 (switch), to re-rout the optical channel with the carrier wavelength λ1, so that it would arrive to the node 82 via a different optial path 71-76-78.

The second option of traffic control operation is controlling the node 80 (OADM) to cause dropping of the channel λ1 and further adding this same channel to the same OADM 80 after being regenerated by a regenerating unit 92. Such a rerouting operation retains the channel on the same optical path (i.e.,

the number of channels in the trail does not change), though enables reduction of the non-linearity effects

Another optional traffic management operation is reducing bit rate of transmission in the optical channel with the carrier wavelength $\lambda 1$.

For example, when the traffic control unit 90 receives chirp measurements from the block 84 and, "keeping in mind" the bit rate of the optical channel $\lambda 1$, obtains the corresponding BER from the look-up table stored in its memory, it compares the obtained BER value with some pre-selected acceptable BER. Upon the comparison, the control unit 90 is able to decide whether the current bit rate is still applicable. If the obtained BER exceeds the acceptable BER, the control unit may issue an order that a reduced bit rate should be used in the channel.

If there is a vacant optical channel (not shown) in the optical path, the traffic control unit may decide to perform a so-called "frequency hopping" operation, i.e., to transmit the data of the problematic optical channel via the vacant channel.

While the invention has been described with reference to a number of specific examples, it should be appreciated that other versions of the method can be proposed, and equipment capable of performing the inventive method can be designed. Such various versions of the method and the suitable equipment are to be considered part of the invention and are defined by the claims that follow.